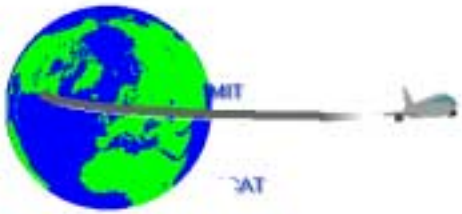

ANALYSIS OF THE OPERATIONAL IMPACT OF REMOTE-SENSING OF AIRCRAFT ICING

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Objectives

- **Identify the key operational issues associated with the introduction of information from remote sensing of aircraft icing, in the context of aviation weather information**
  - Information Requirements
  - Dissemination Paths
  - Information Presentation
  - Procedural Implications
  - Icing Severity Level Definition

Feedback between Remote Sensing Capability and Operations

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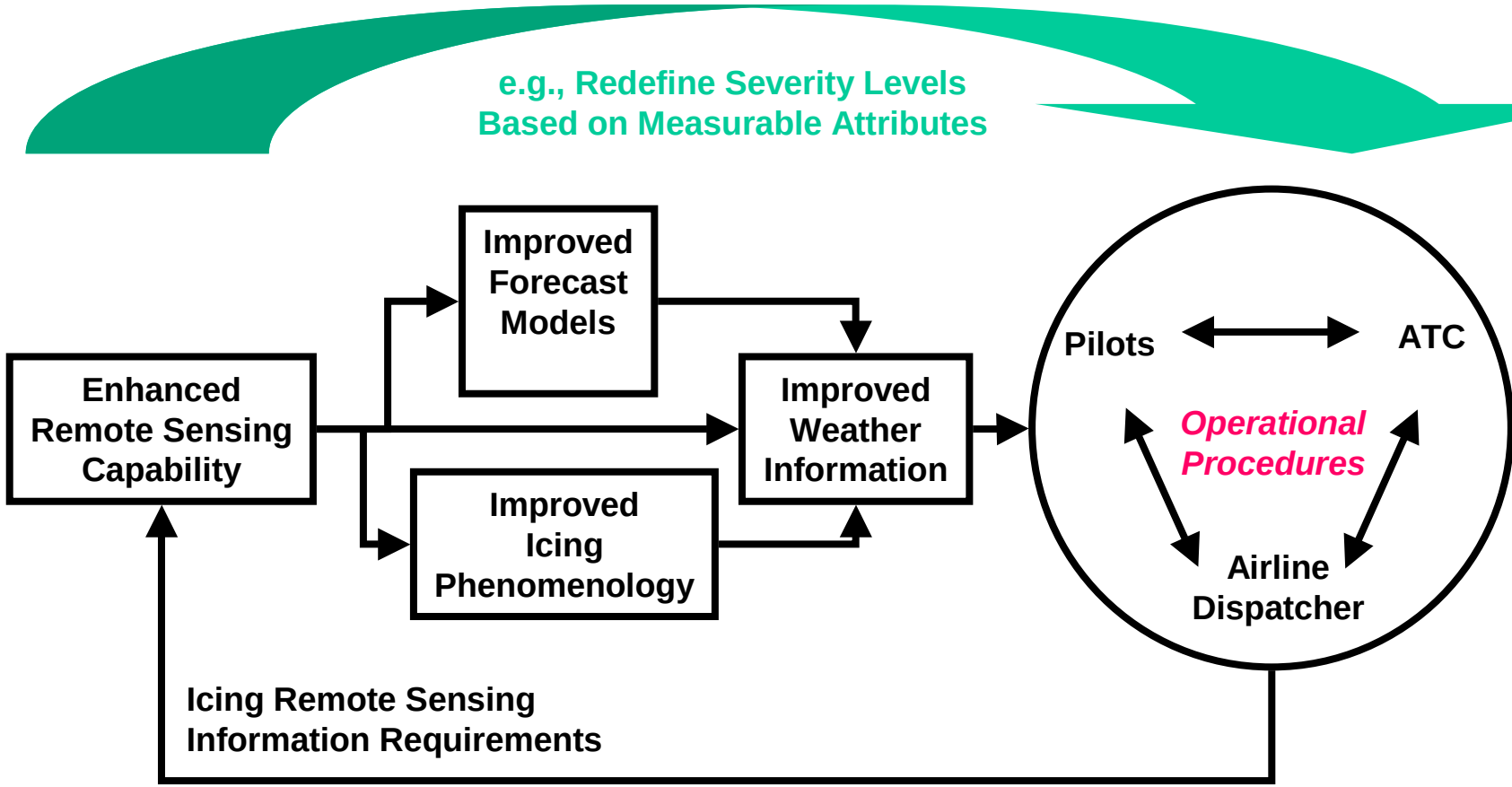

Human-Centered Approach

Closed Loop Feedback Process

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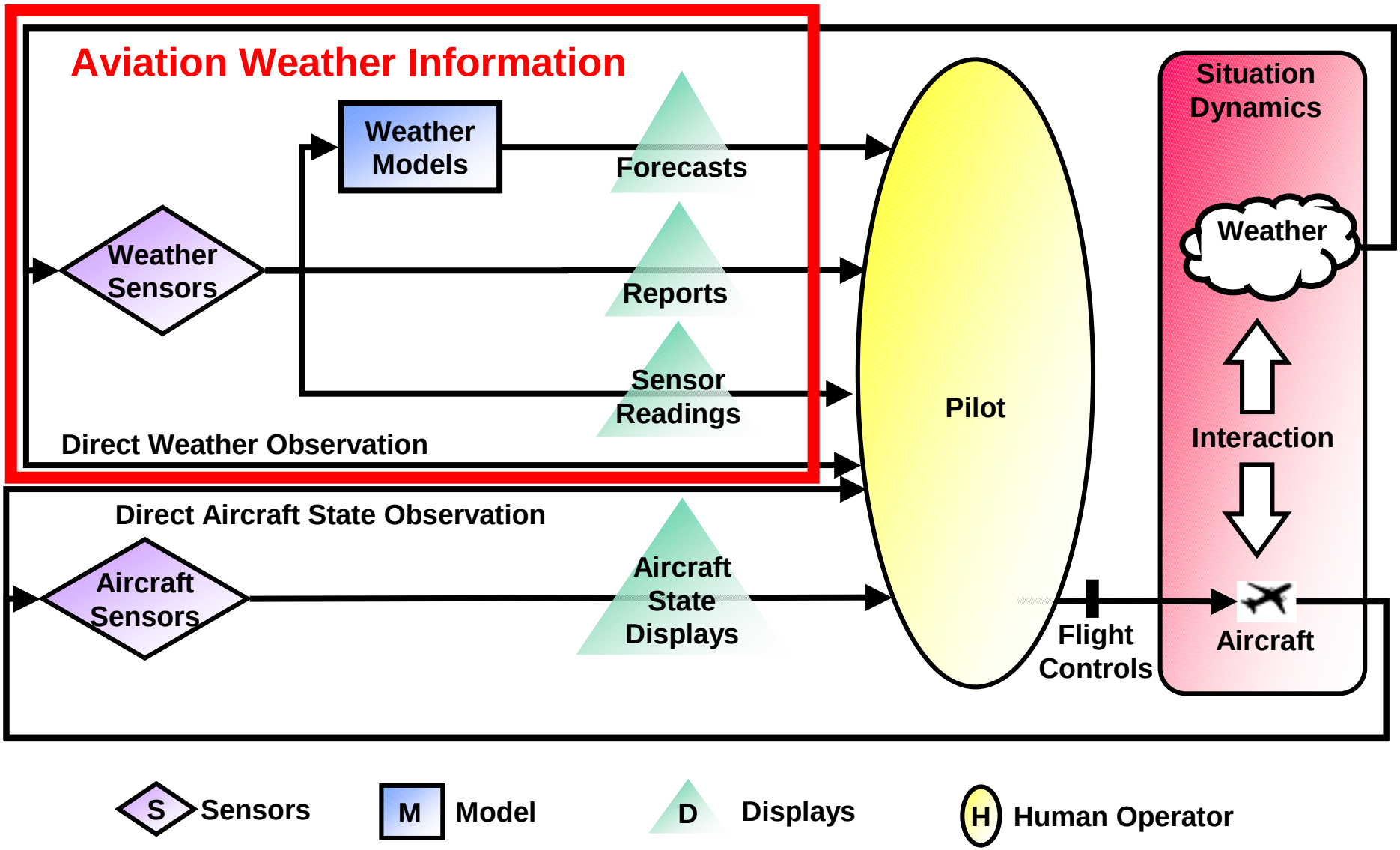
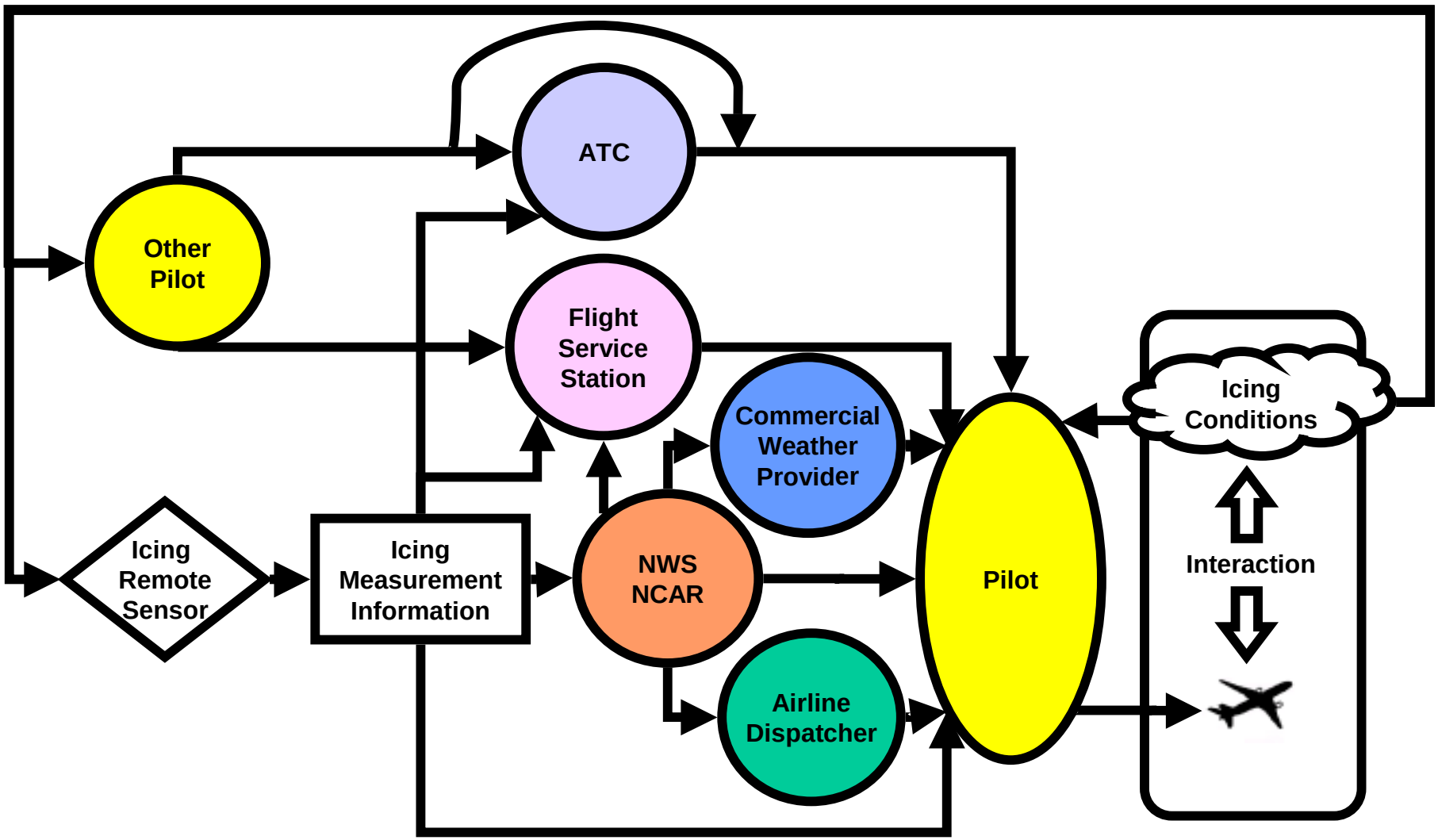
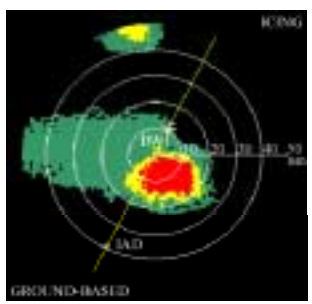


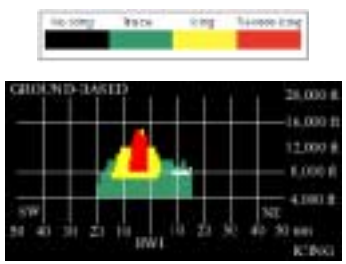
Users of Icing Information

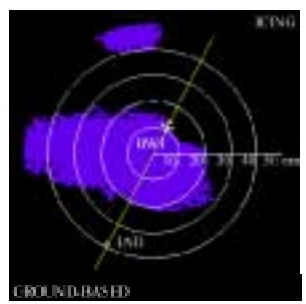


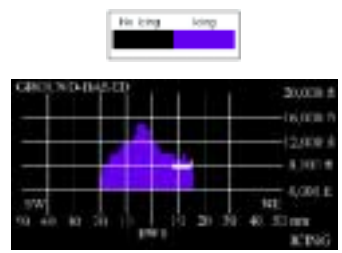
Prior Work (Work for MS)
Human-Centered Approach

- **Determined Information Needs from Icing Information Systems in a Web-Based Survey (n=589)**
  - *Alerting of icing hazards*
  - *Depiction of icing potential along planned route*
  - *Identification of safe alternatives*
    - *Existence of escape and avoidance options*
  - *Need to develop and maintain pilot trust / credibility*
    - *Issues of pilots' response to false alarm / over-warning*
- **Evaluated Display Options in a Web-Based Experiment (n=230)**
  - *Ground-based icing remote sensing most useful near-term product*
  - *Icing information needed along vertical dimension*
  - *High value of depicting non-icing zones with high confidence*









Current Work (PhD)
Considers Previous Hazard Alerting

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- **Fundamental Differences Between Weather and Other Hazards**
  - Soft vs. Hard
    - *Hard Hazard: Terrain, Traffic*
  - Multi-Attribute Field
    - *Spatially Distributed*
    - *Temporally Varying*
  - Exposure-Dependent and Exposure Independent Hazards
  - Multiple Types of Uncertainties
    - *Spatial Distribution of the Weather Field*
    - *Risk of Aircraft Interaction with Weather Field*
    - *Temporal Evolution of the Weather Field*
    - *Four-Dimensional Trajectory of Aircraft*

Weather Situation Dynamics Abstraction

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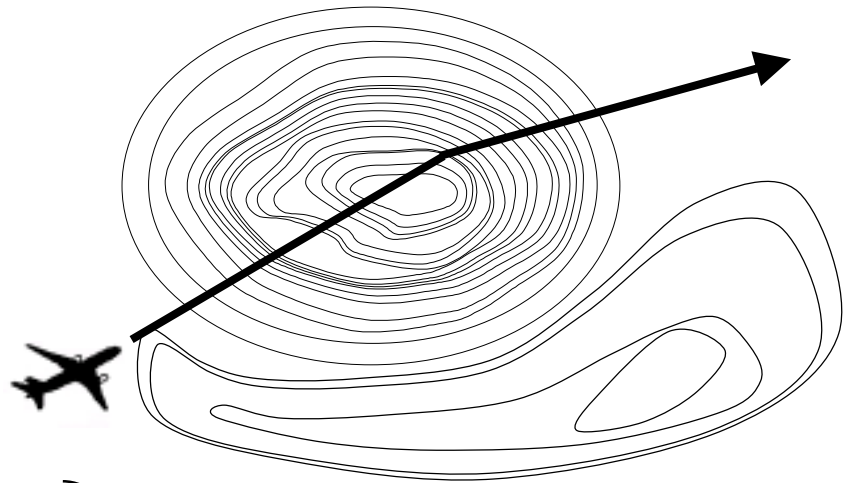
Aircraft Trajectory
Modeled by a state vector X that describes the aircraft states along path (e.g., position, velocity, acceleration, configuration)

$$\mathbf{X}\begin{pmatrix} x_1(t) \\ x_2(t) \\ \dots \\ x_i(t)] \end{pmatrix}$$



Weather Field
Modeled by a multi-attribute field F that has spatially distributed and temporally varying properties f_j (e.g., wind, temperature, liquid water content, etc.)

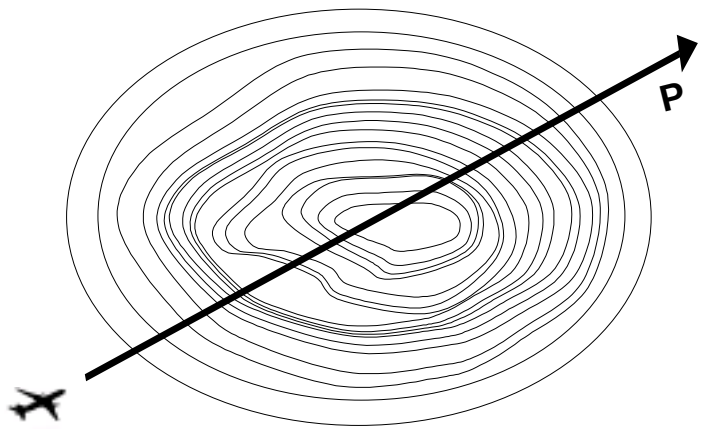
$$\mathbf{F}\begin{pmatrix} f_1(x,y,z,t) \\ \dots \\ f_j(x,y,z,t) \end{pmatrix}$$

Risk
Function of the interaction between the weather field and the aircraft state vector

Preliminary Risk Characterization Model

- **Exposure-Dependent Hazard Space (Small Probabilities)**
  e.g., Icing

$$P(L) \cong R_P = \int_P \rho(s)ds$$



$P(L)$ **Probability of Loss Event**

R_P **Risk along Assumed Path**

P **Assumed path**

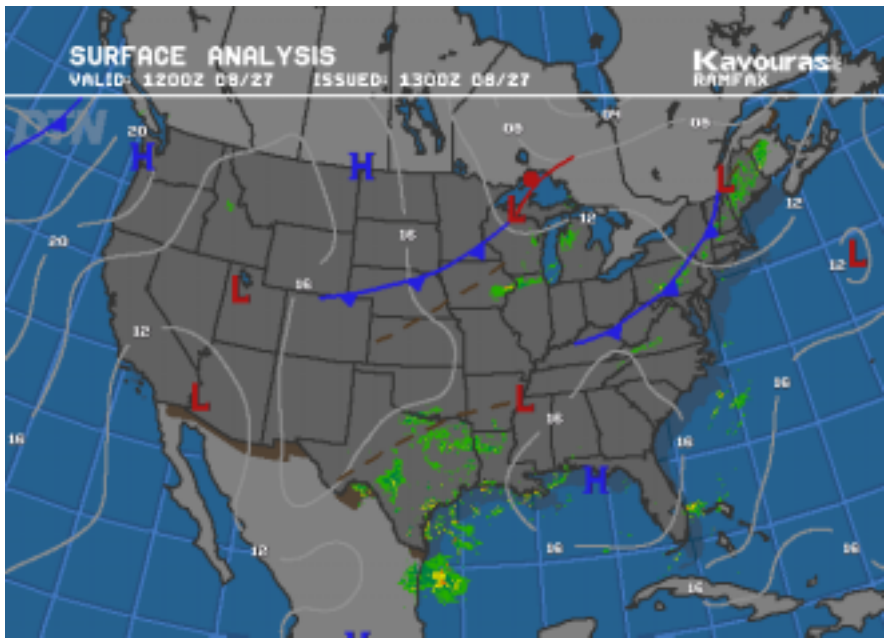
$\rho(s)$ **Risk density**

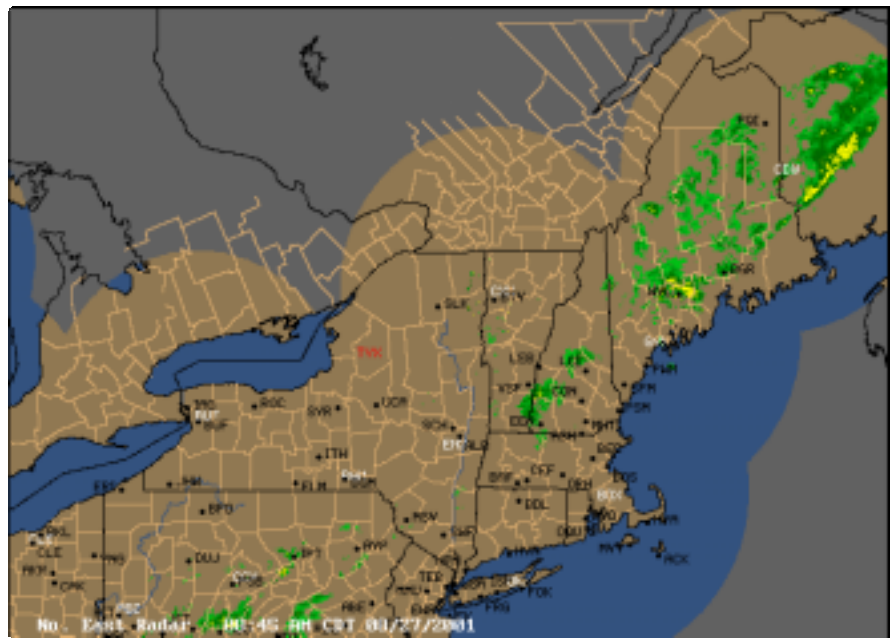
s **Distance along path related to the field coordinates as**

$$s = \int \sqrt{\left(\frac{dx}{dt}\right)^2 + \left(\frac{dy}{dt}\right)^2 + \left(\frac{dz}{dt}\right)^2}\, dt$$

Weather Time Scale Analysis

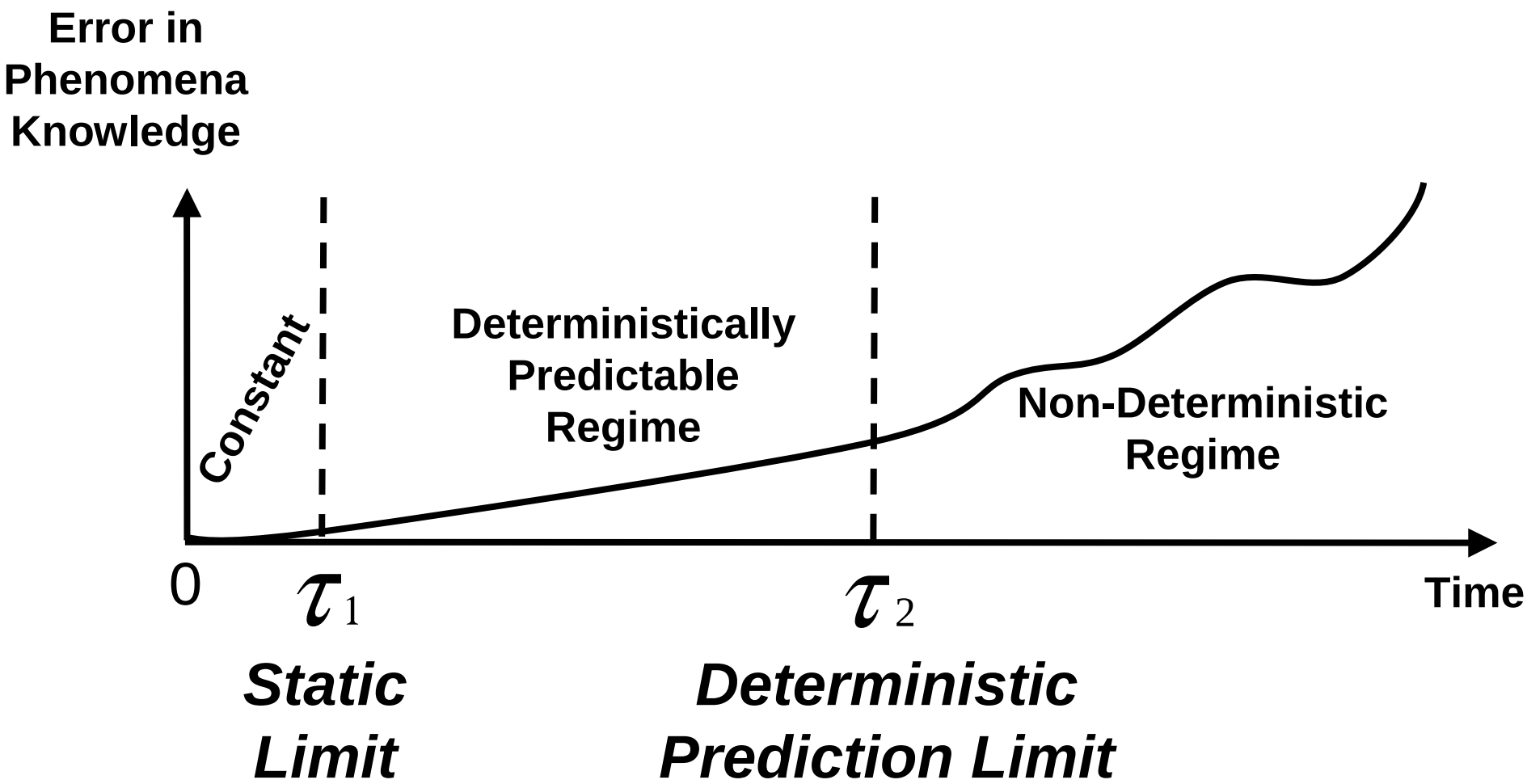
Capturing Dynamic Effects



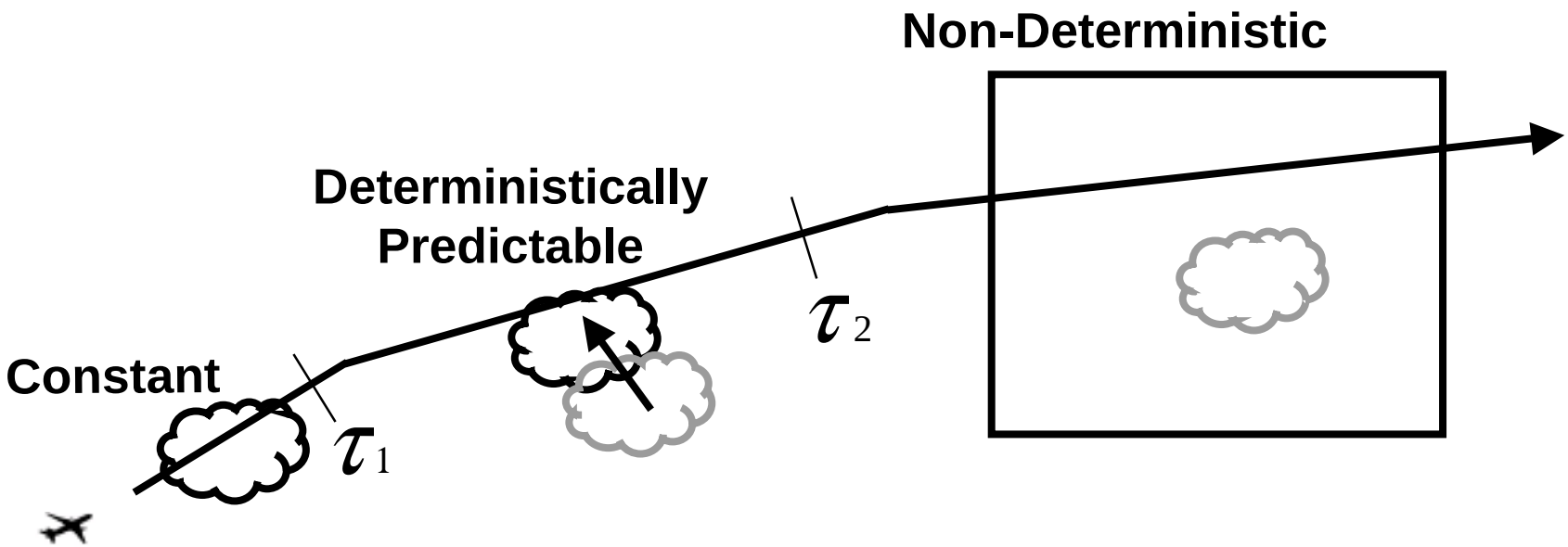


Weather Time Scale Analysis

Concept



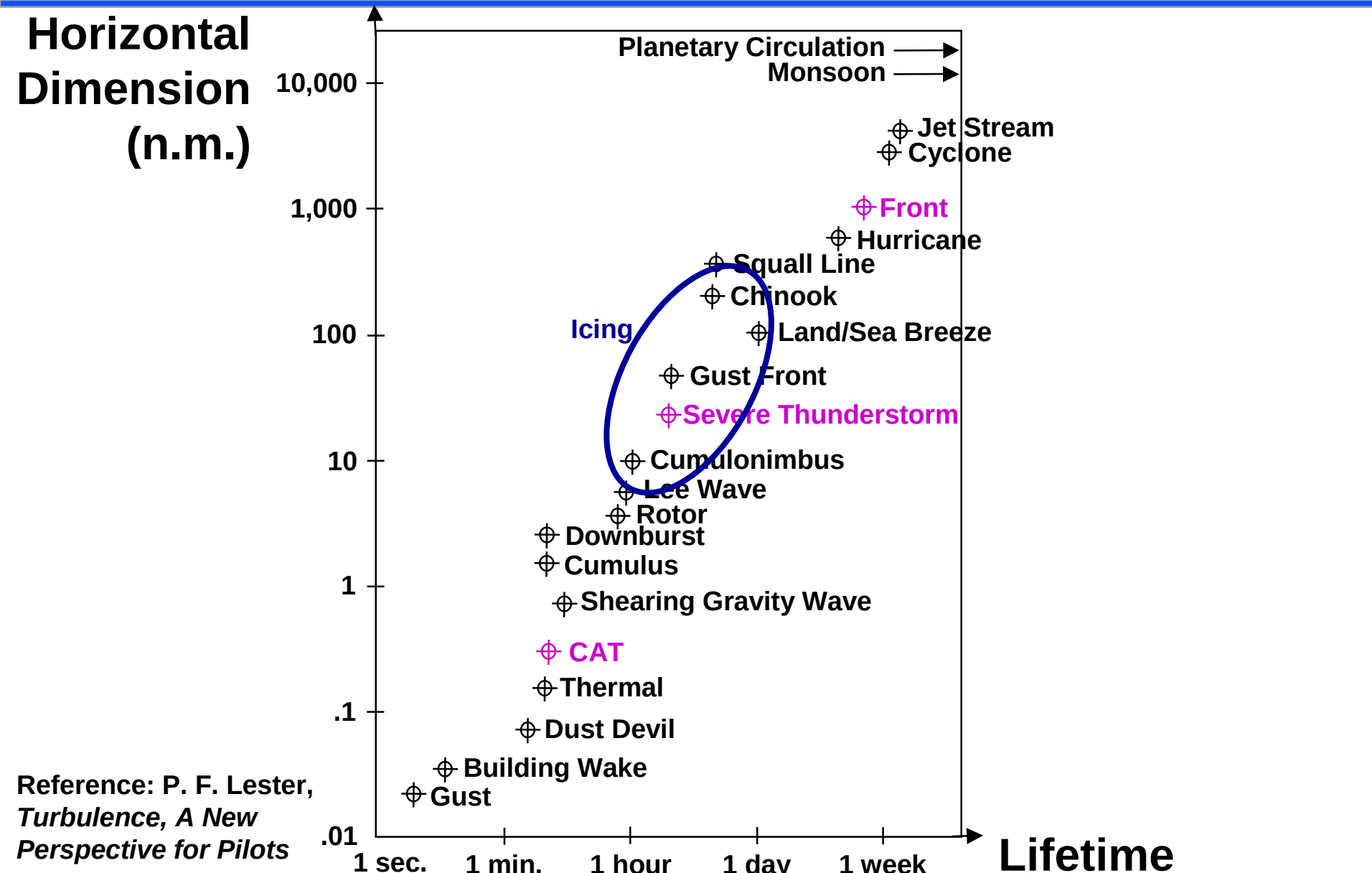
Implications for Weather Information Needs



What are the Implications for Display and Visualization?

Weather Time Scale Analysis

Meteorological Disturbances



Reference: P. F. Lester, *Turbulence, A New Perspective for Pilots*

Weather Time Scale Analysis

Notional Timescales

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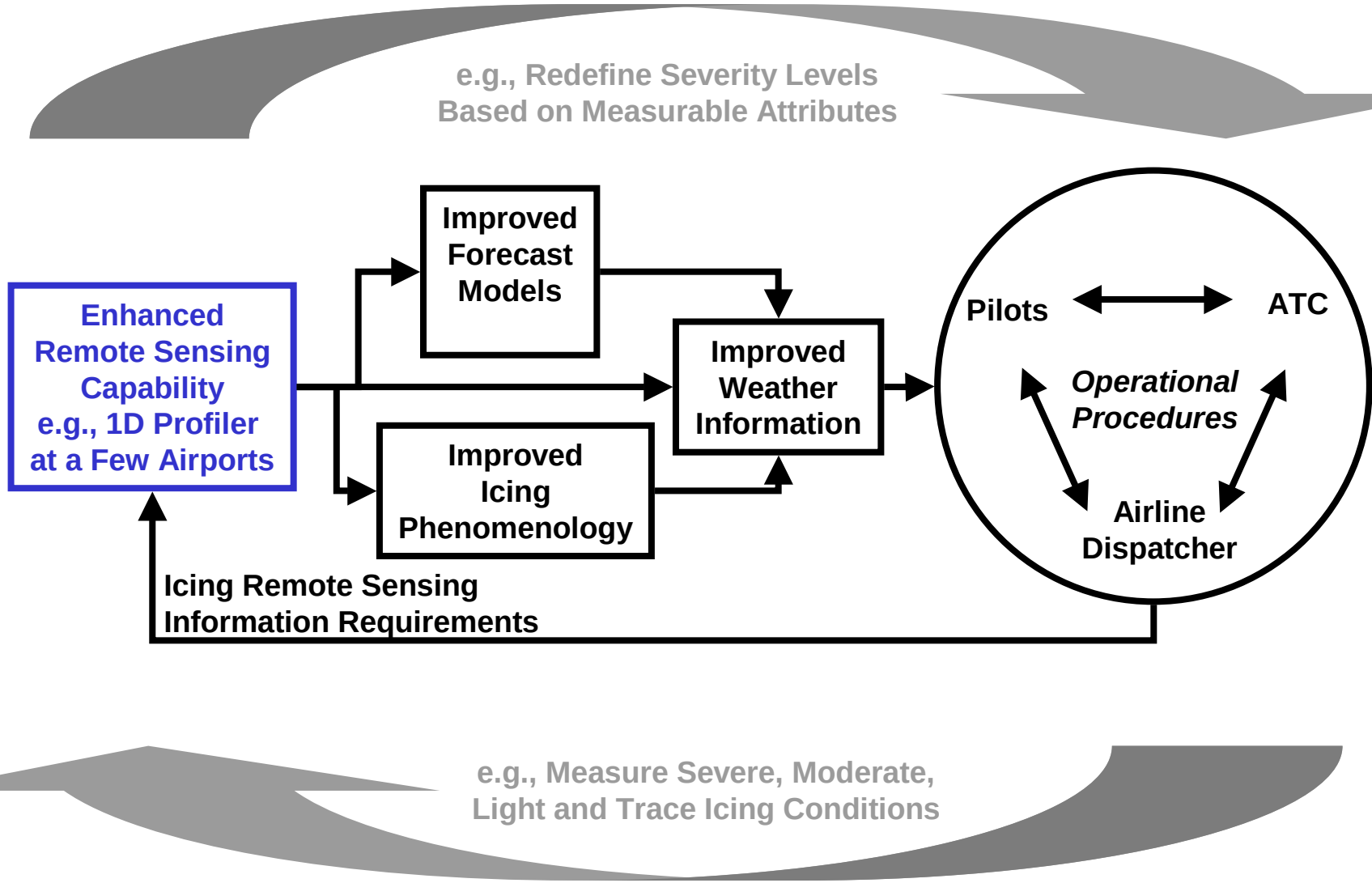
	τ_1	τ_2
Icing	**5-30 Minutes**	**Hours**
Thunderstorms	**5-30 Minutes**	**Hours**
Fronts	**Hours**	**½ Day – 1 Day**
Clear Air Turbulence	**Minutes**	**30 Minutes**
Microbursts	**Minutes**	**10 Minutes**
Fog	**Minutes-Hours**	**Minutes-Hours**
Hurricane	**Hours**	**Days**
Surface Winds	**Minutes**	**30 Minutes**
Ceilings	**5-30 Minutes**	**Minutes-Hours**
…		

1D Profiler Case Study



1D Icing Profiler Assumptions

- **Assumptions***
  - 1-D vertical sounding
  - Between the surface and 10 km
  - Spatial resolution
    - *100 m increments between surface and 1 km*
    - *0.25 km increments between 1 and 10 km*
  - 4 identifiable levels of LWC (TBD)
  - Update rate of 8-minutes or better
  - Radiometers installed at a limited number of airports initially

**Based on Informal Conversation with NASA*

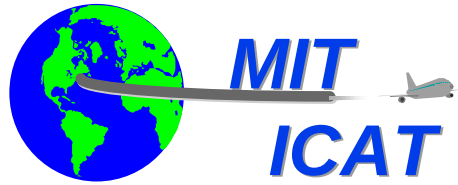
Pilot Information Requirements

	Planning for (Non-Deterministic Regime)	Avoidance (Deterministic Regime)	Escape (Deterministic Regime)
Non-Equipped	- Potential for Icing Conditions - Potential for Ice Free Zones to Support Options	- Location of Icing Conditions - Location of Icing-Free Zones	- Location of Icing-Free Zones
Equipped Turbo-Prop	- Potential for Icing Conditions - Potential for Severe Icing Conditions - Potential for Ice Free Zones to Support Options	- Location of Icing Conditions - Location of Severe Icing Conditions - Location of Icing-Free Zones	- Location of Icing-Free Zones - Location of Zones Free of Severe Icing
Equipped Jet	-Potential for Severe Icing Conditions - Potential for Zones Free of Severe Icing to Support Options	- Location of Severe Icing Conditions - Location of Zones Free of Severe Icing	- Location of Zones Free of Severe Icing

Note: In All Cases, the Information Is Required Along Planned Trajectory

Icing
Severe Icing

Other Information Requirements



- **Air Traffic Controllers**
  - Traffic Flow Planning
    - *Potential for icing conditions affecting airports and routes*
  - Supporting Avoidance
    - *Location of icing conditions (for non-equipped pilots and equipped turbo-prop pilots)*
    - *Location of severe icing (for equipped pilots)*
  - Supporting Escape
    - *Location of zones free of icing conditions (for non-equipped pilots and equipped turbo-prop pilots)*
    - *Location of zones free of severe icing (for equipped pilots)*
- **Airline Dispatchers**
  - Route Planning
    - *Potential for icing conditions affecting airports and routes*
  - Supporting Avoidance
    - *Location of icing conditions (for non-equipped pilots and equipped turbo-prop pilots)*
    - *Location of severe icing (for equipped pilots)*

ATC Info Requirements Example

Disruption to Flow Planning

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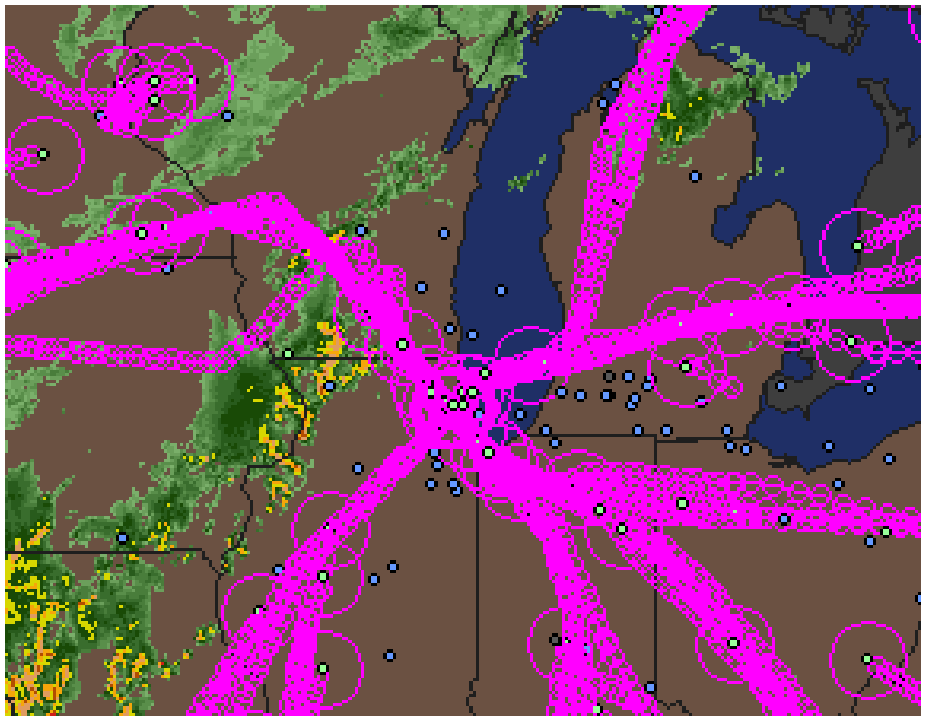
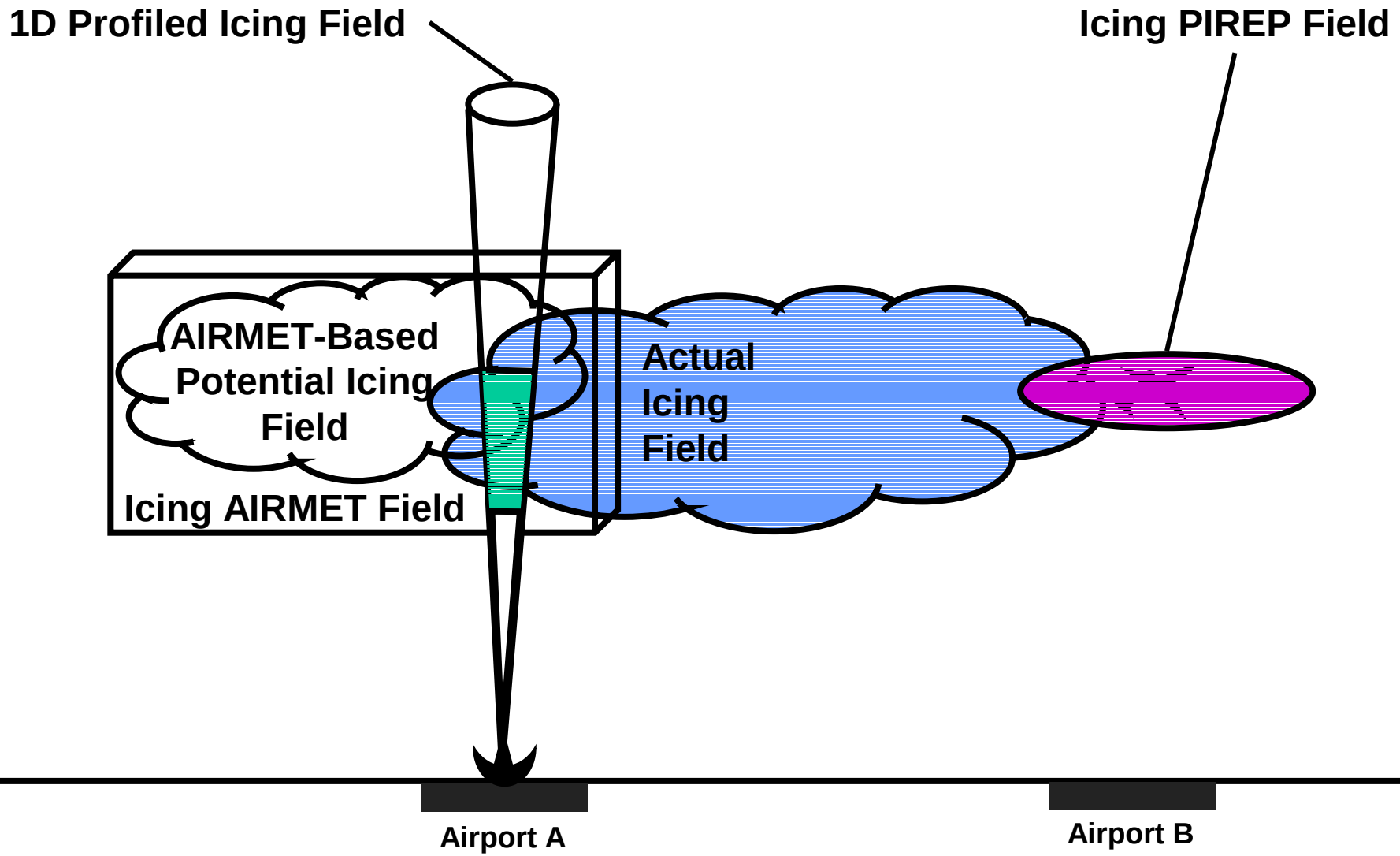
Organized Flow at ORD



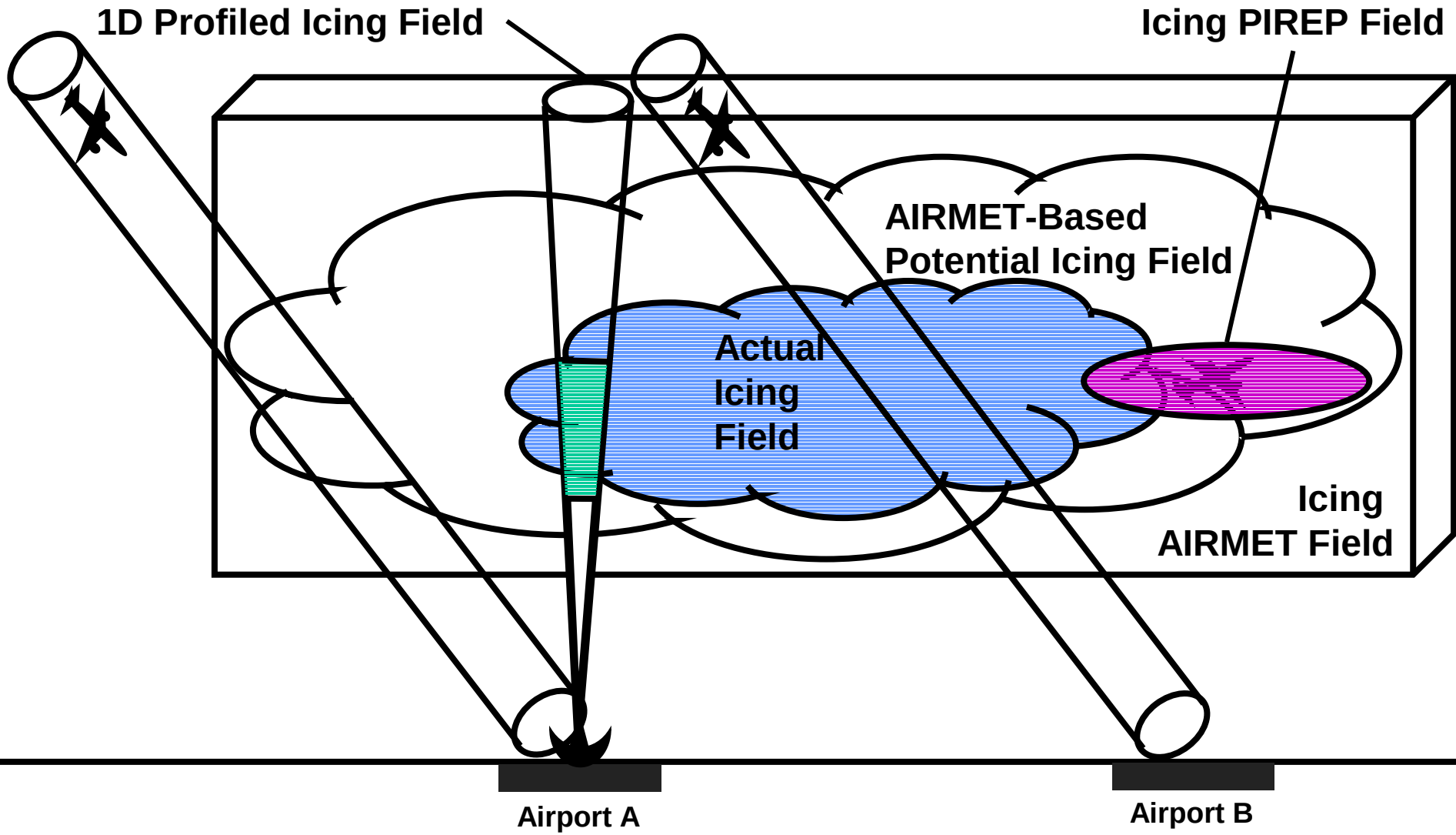
NW Corner Post at ORD
blocked by Convective Weather

Courtesy of Jonathan Histon

1D Profile in Context of Relevant Icing Fields



Relationship of Fields to Approach Trajectories



1D Icing Profile Example

Key Identified Uses

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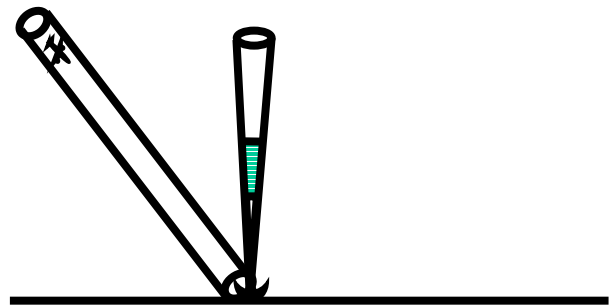
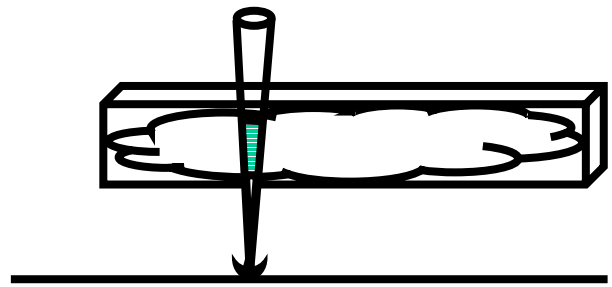
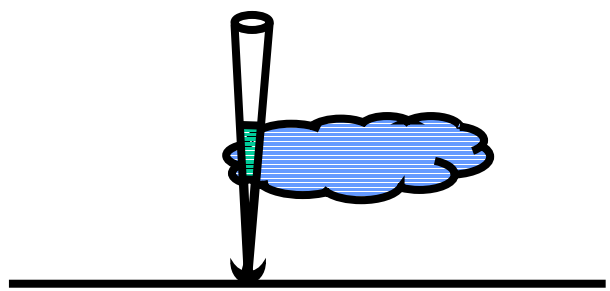
1. **Provide near real-time measurements to pilots at equipped airports**
   - Altitude of icing & icing-free conditions
   - Intensity of icing conditions



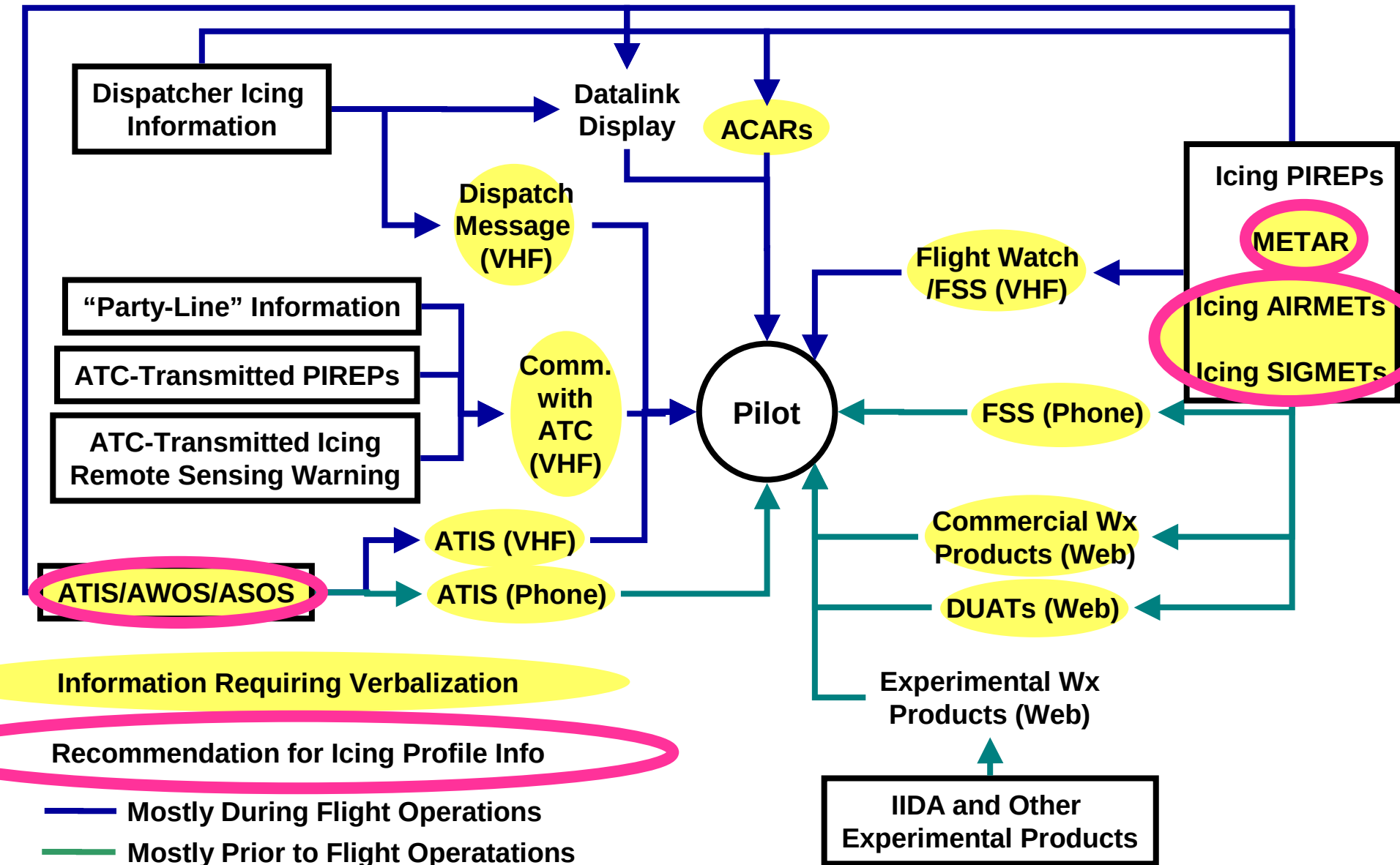
2. **Provide data that can be used to validate icing forecasts**
   - AIRMETs
   - SIGMETs
   - IIDA / IIFA



3. **Provide data that can be used to improve our understanding of icing phenomenology and forecasts**



Dissemination of 1D Profiler Information



ATIS Based on 1D Profiler

Strawman Proposal

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No Icing

"No icing conditions are detected over the [XXX] airport."

Single Layer

"Icing conditions measured over the [XXX] airport.
Icing detected in a single layer, tops at [a] [thousand/hundred] feet, no icing below [b] thousand feet."

Multiple Layers

"Icing conditions measured over the [XXX] airport.
Icing detected in [n] layers between [c] and [d] thousand feet.
Top of icing is [e] thousand feet; no icing below [f] [thousand/hundred] feet.
No icing detected between [g] and [h] thousand feet."

Severe Icing

"Severe icing conditions measured over the [XXX] airport.
Top of icing is [m] thousand feet; no icing below [o] [thousand/hundreed] feet.
Severe icing detected in [a single layer/n layers] between [i] & [j] thousand feet.
Icing detected in [a single layer]/[n layers] between [k] and [l] thousand feet."

AIRMET/SIGMET Based on 1D Profiler - *Strawman Proposal*

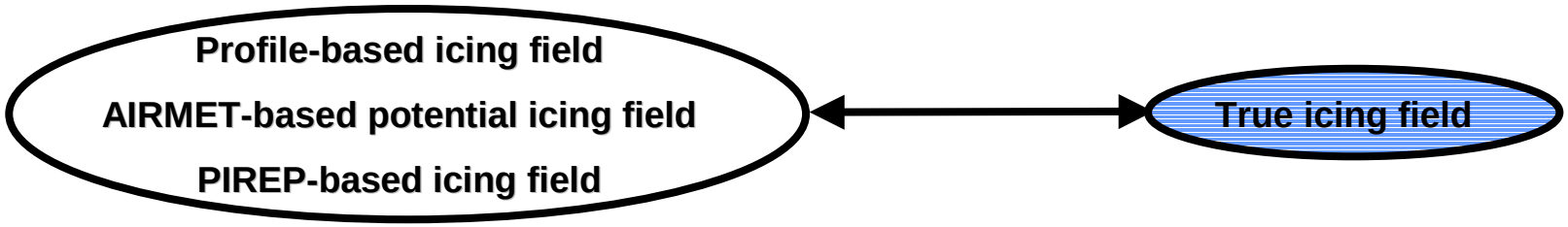
"Airmet Zulu for icing and freezing level valid until xxxxxx.
Occasional moderate rime/mixed icing in clouds and precipitation between [a] and [b] thousand feet in WA, and between [c] and [d] thousand feet in OR.

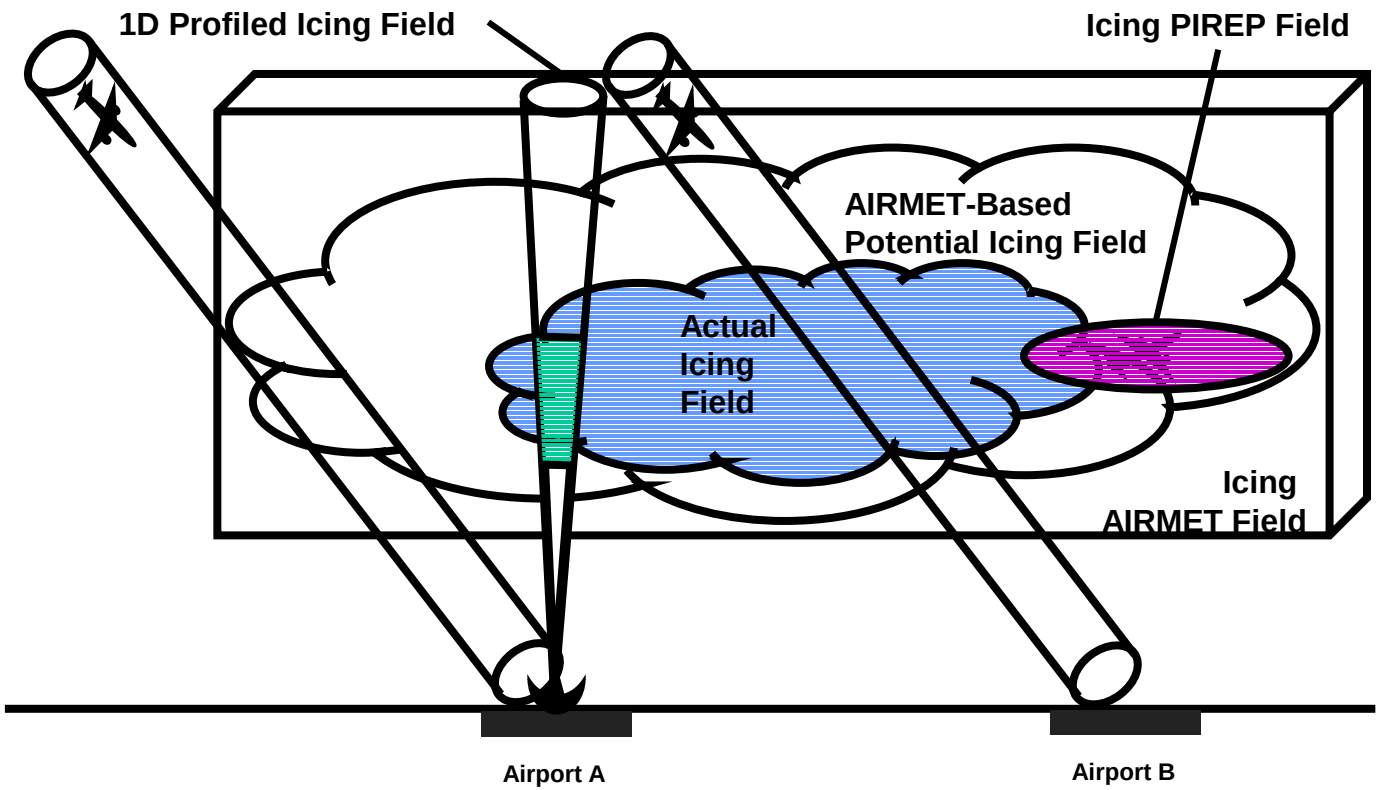
Freezing level in WA West of Cascades at [e] thousand feet, lowering by xxZ; at/near the surface with multiple freezing levels between [f] and [g] thousand feet.

Icing conditions measured over the [XXX] airport at xxZ
Icing detected in [a single layer], tops at [h] thousand feet; no icing below [I] thousand feet."

1D Icing Profiler
Emerging Issues

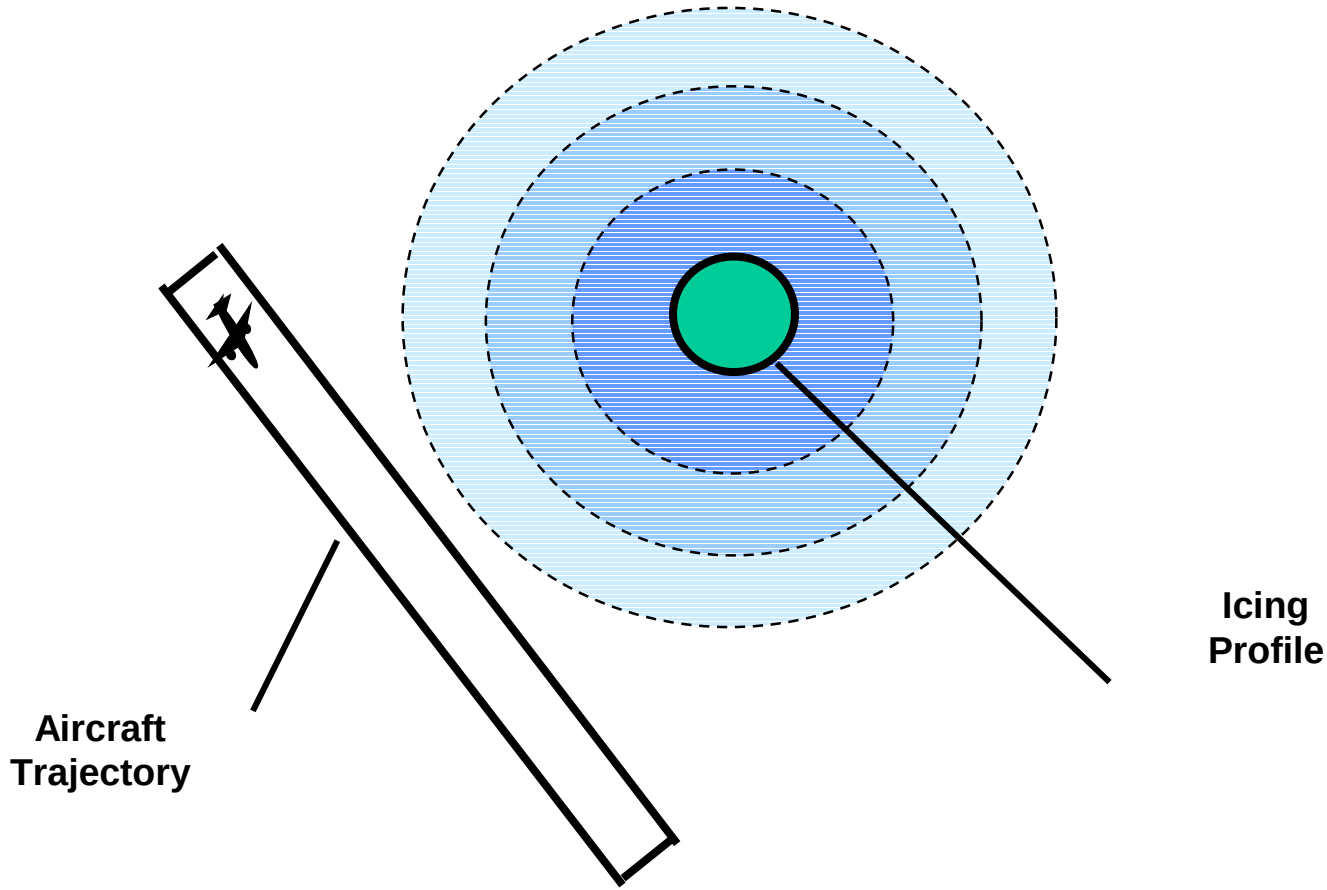
- **How should users deal with mismatch between the “icing fields”?**





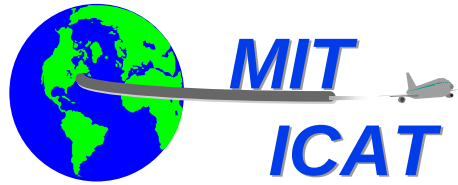
1D Icing Profiler
Emerging Issues (Cont.)

- **What spatial extent of icing conditions should be inferred from an icing profile?**



TOP VIEW

1D Icing Profiler
Emerging Issues (Cont.)



- **How should information from icing profiles be used in the context of the definition for “known icing”?**
- **What should the 1D profiler LWC levels be?**
- **What is the correlation between profiler levels and icing definitions?**
  - Severe
  - Moderate
  - Light
  - Trace

Impact of Remote Sensing on Definitions of Procedures

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- **FARs**

91.527 (b) and [135.227 (c)]

Except for an airplane that has ice protection provisions (…), no pilot may fly

(1) Under IFR into ***known or forecast [light or] moderate icing conditions***; or

(2) Under VFR into ***known light or moderate icing conditions*** unless the aircraft has functioning de-icing or anti-icing equipment protecting each propeller, windshield, wing, stabilizing or control surface, and each airspeed, altimeter, rate of climb, or flight attitude instrument system.

91.527 (c) and 135.227 (e)

Except for an airplane that has ice protection provisions (…), no pilot may fly an airplane into ***known or forecast severe icing conditions***.

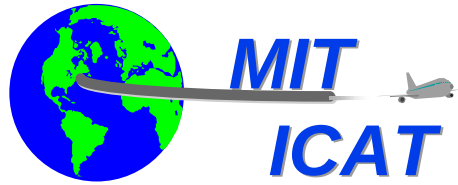
91.527 (d) and 135.227 (f)

If current weather reports and briefing information relied upon by the PIC indicate that the forecast icing condition that would otherwise prohibit the flight will not be encountered during the flight because of ***changed weather conditions since the forecast***, the restrictions in [the above] paragraphs based on forecast conditions do not apply.

121.629

(a) No person may dispatch or release an aircraft, continue to operate an aircraft en route, or land an aircraft when in the opinion of the pilot in command or aircraft dispatcher (domestic and flag operations only), icing conditions are expected or met ***that might adversely affect the safety of the flight***.

Impact of Remote Sensing on Definitions of Procedures



- **Proposed Definitions (Federal Register, 2000)**

  Known or Observed/Detected Icing

  Actual ice observed visually on the aircraft by the flight crew, or identified by on-board sensors

  Forecast Icing Conditions

  Environmental conditions expected by the approved weather service to be conducive to the formation of in-flight icing on aircraft

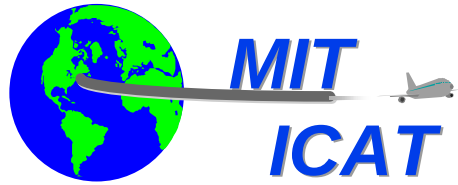
  Potential Icing Conditions

  Atmospheric conditions conducive to ice accretion on aircraft components. Visible moisture and temperatures colder than a specific temperature typically define these conditions. The aircraft manufacturer normally defines these conditions

  Known Icing Conditions

  Atmospheric conditions in which the formation of ice is observed or detected in flight. (Note: Because of the variability in space and time of atmospheric conditions, the existence of a report of known icing does not assure the presence of intensity of icing conditions at a later time, nor can a report of no icing assure the absence of icing conditions at a later time.)

Impact of Remote Sensing on Definitions of Procedures



- **The introduction of information from remote sensing of aircraft icing will:**
  - Change the operational procedures currently in place
  - Change the definition of “known icing” used in procedures
- **Emerging questions on the use of 1D icing profile information**
  1. Should it be legal to shoot an approach at an airport where measurements indicate the presence of icing
     - *At altitudes below the minima of standard arrival procedures?*
     - *At altitudes above the minima of standard arrival procedures?*
  2. Should it be legal to take-off for an airport or file as an alternate an airport where icing (or severe icing) conditions are currently detected?
  3. Should it be legal to execute 1 and 2 if the destination (or alternate) is nearby another airport where icing (or severe icing) conditions are detected?
  4. Do the new definitions and procedures in place provide the right operational incentives?

     e.g., pilot decides to avoid an airport equipped with 1D icing profile information to comply with regulations, and may chose to land at an airport where prospects are worse
- **Resistance may be found regarding the introduction of information and/or procedures resulting from remote sensing of aircraft icing**
  - Pilots
    - *Due to trust issues and restrictions*
  - ATC
    - *Due to workload/responsibility issues*

Conclusions & Recommendations

1. **Enhanced remote sensing capabilities promise to help improve:**
   1. Understanding of icing phenomenology
   2. Forecast models
   3. Icing information to key decision-makers in the operational environment (e.g., pilots, airline dispatchers and ATC)
2. **The introduction of operational 1D profilers will require adjustments in operational procedures.**
3. **The most likely initial operational applications of 1D profilers would be in METARs, ATIS, AIRMETs and SIGMETs.**
4. **The most desirable strategy for introducing 1D profiler information involves using an experimental web-based product and collecting feedback from the operational community**
5. **A better understanding of the operational perception of hazardous weather fields should help**
   - Define operational procedures
   - Identify dissemination paths
   - Guide sensor refinement and more advanced sensor development
6. **In order to support remote sensing scanning requirements, a need has been identified to evaluate advanced visualization of spatially and temporally varying icing fields**